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13. ABSTRACT *(Maximum 200 Words)*

The research summarized in this report is aimed at developing image understanding (IU) algorithms and systems that have performance prediction and learning capabilities and that can improve their performance with experience, in terms of quality of results, processing speed and matching with the user's perception. The following scientific problems are addressed:

(a) Fundamental theory for predicting the performance of object recognition systems and its validation on SAR images,
(b) Automatic methods for recognizing articulated, occluded and configuration variants of targets in SAR images and video,
(c) Adaptive learning integrated target recognition algorithms/systems, and
(d) Learning visual concepts in images/videos with user interaction and experience over time.

The research presented makes a significant contribution to real-world applications which require robust high performance automated systems that can recognize objects in reconnaissance imagery acquired under dynamically changing conditions and for systems that can efficiently extract meaningful information from enormous image/video databases.

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This final report describes the progress and accomplishments made on the project entitled, "Learning Integrated Visual Databases for Image Exploitation," during the period from March 15, 1997 to August 31, 2002.

1. OBJECTIVES:

The DoD has critical needs for robust high performance automated systems that can recognize objects in reconnaissance imagery acquired under dynamically changing conditions and for systems that can efficiently extract information from enormous image databases. Our research addresses two interrelated problems with the effectiveness and efficiency of automated/semi-automated techniques for image understanding. *First*, the lack of robustness in algorithms and systems for object recognition with changing environments and extended operating conditions. *Second*, the lack of scalable intelligent strategies for quickly extracting meaningful information from enormous, dynamically changing image databases. Our research is aimed at developing image understanding (IU) algorithms and systems that have performance prediction and learning capabilities and that can improve their performance with experience, in terms of quality of results, processing speed and matching with the user's perception.

The specific subgoals explored are:

Fundamental theory for predicting the performance of object recognition systems and its validation on SAR images,

Automatic methods for recognizing articulated, occluded and configuration variants of targets in SAR images and video,

Adaptive learning integrated target recognition algorithms/systems, and

Learning visual concepts in images/videos with user interaction and experience over time.

We have developed promising fundamental approaches and obtained excellent results to solve some of the crucial problems in image understanding and image databases that will have strong impact in solving real-world DoD applications. In the following we describe the major accomplishments achieved during the reporting period. Specific aspects of the research are given in greater detail in separate papers published in journals and major conferences. A list of all the published papers is also presented.

2. RESEARCH ACCOMPLISHMENTS

2.1 Recognition Performance Prediction and Fundamental Performance Bounds

We have developed fundamental techniques for predicting the performance of model-based object recognition systems in the presence of data uncertainty, occlusion and clutter. These techniques determine fundamental performance bounds (lower and upper) and set the limits on what is possible for a feature-based object recognition system. The new techniques capture the structural similarity between model objects, which is a fundamental factor in determining the recognition performance. We have done experiments to successfully *validate* the theory by comparing predicted PCR plots with ones that are obtained experimentally using MSTAR SAR data collected by AFRL for target recognition research under extended operating conditions.

In addition, we have developed SAR ATR algorithms that explicitly account for model similarity. In this work we optimize recognition models for SAR signatures of vehicles to improve the performance of a recognition algorithm under the extended operating conditions of target articulation, occlusion and configuration variants. The recognition models are based on quasi-invariant local features, scattering center locations and magnitudes. The approach determines the similarities and differences among the various vehicle models. Methods to penalize similar features or reward dissimilar features are used to increase the distinguishability of the recognition model instances. Extensive experimental results, in terms of confusion matrices and ROC curves, demonstrate the improvements in recognition performance for real SAR signatures of vehicle targets with articulation, configuration variants and occlusion.

Journal Publications:

1. M. Boshra and B. Bhanu, "Predicting performance of object recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No. 9, pp. 956-969, 2000.

2. M. Boshra and B. Bhanu, "Predicting an upper bound on SAR ATR performance," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 3, pp. 876-888, 2001.

3. B. Bhanu and G. Jones, "Increasing the discrimination of SAR recognition models," *Optical Engineering*, Vol. 41, No. 12, December 2002.

2.2 Automatic Target Recognition in Extended Operating Conditions ---- Articulated, Occluded and Configuration Variants of Targets

We have developed a model-based SAR recognition system that uses standard non-articulated models of objects to recognize the same objects in non-standard, occluded and articulated configurations. The system is based on the quasi-invariance of radar scatterer locations and magnitudes, while an accumulation of evidence from local features recognition approach successfully handles articulation, occlusion and configuration variants.

The independent views in SAR are an opportunity for increased recognition performance. The focus of this research has been to optimize the recognition of vehicles using multiple SAR recognizers. Both recognition from multiple look angles and multiple recognizers with different parameter tunings are investigated. Extensive experimental recognition results, in terms of receiver operating characteristic (ROC) curves, show the effects on recognition performance for MSTAR vehicle targets with articulation, configuration variants and occlusion.

Journal Publications

1. G. Jones and B. Bhanu, "Recognition of articulated and occluded objects," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 21, No. 7, pp. 603-613, 1999.

2. B. Bhanu and G. Jones, "Recognizing target variants and articulations in synthetic aperture radar images," *Optical Engineering*, Vol. 39, No. 3, pp. 712-723, 2000.

3. G. Jones and B. Bhanu, "Recognizing occluded objects in SAR images," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 1, pp. 316-328, 2001.

4. G. Jones and B. Bhanu, "Recognizing articulated targets in SAR images," *Pattern Recognition*, Vol. 34, No. 2, pp. 469-485, 2001.

5. J.S. Ahn and B. Bhanu, "Model-based recognition of articulated objects," *Pattern Recognition Letters*, Vol. 23, No. 8, pp. 1019-1029, 2002.

6. B. Bhanu and G. Jones III., "Multiple look angle SAR recognition," *International Journal of Imaging and Graphics*. Accepted.

2.2.1 Stochastic Models for Recognition

Recognition of occluded objects in synthetic aperture radar (SAR) images is a significant problem for automatic target recognition. Stochastic models provide some attractive features for pattern matching and recognition under partial occlusion and noise. We develop a hidden Markov modeling (HMM) based approach for recognizing objects in synthetic aperture radar (SAR) images. We identify the peculiar characteristics of SAR sensors and using these characteristics we develop feature based multiple models for a given SAR image of an object. The models exploiting the relative geometry of feature locations or the amplitude of SAR radar return are based on sequentialization of scattering centers extracted from SAR images. In order to improve performance we integrate these models synergistically using their probabilistic estimates for recognition of a particular target at a specific azimuth. Experimental results are presented using both synthetic and real SAR images.

Journal Publication

1. B. Bhanu and Y. Lin, "Stochastic models for recognition of occluded objects," *Pattern Recognition*, Revised September 2002.

2.2.2 Recognition of Human Articulated Motion

Current gait recognition approaches only consider individuals walking frontoparallel to the image plane. This makes them inapplicable for recognizing individuals walking from different angles with respect to the image plane. In this research, we develop a kinematic-

based approach to recognize individuals by gait. The new approach estimates 3D human walking parameters by performing a least squares fit of the 3D kinematic model to the 2D silhouette extracted from a monocular image sequence. A Genetic algorithm is used for feature selection from the estimated parameters, and the individuals are then recognized from the feature vectors using a nearest neighbor method. Experimental results show that the approach achieves good performance in recognizing individuals walking from different angles with respect to the image plane.

Reviewed Conference Publications

1. B. Bhanu and J. Han, "Individual recognition by kinematic-based gait analysis," *Proceedings International Conference on Pattern Recognition*, Vol. III, pp. 343-346, 2002.

2.2.3 Moving Shadow Detection

Moving object detection systems generally detect shadows cast by the moving object as part of the moving object. In this work the problem of separating moving cast shadows from the moving objects in outdoor environment is addressed. Unlike other previous work, we provide a method that does not use any geometrical information. Our physics-based approach is based on a new spatio-temporal albedo normalization test and a dichromatic reflection model. The physics based model is used both in the estimation and verification phases. We obtain results for several different video sequences representing a variety of materials and shadows. We achieve excellent results in distinguishing moving objects from their shadows. The results indicate that our approach is robust to a variety of background and foreground materials and varying illumination conditions.

Reviewed Conference Publications

1, S. Sohail and B. Bhanu, "Moving shadow detection using a physics-based approach," *Proceedings International Conference on Pattern Recognition*, Vol. II, pp. 701-704, 2002.

2.3 Adaptation and Learning for Target Recognition

We have developed several techniques based on reinforcement learning for closed-loop target recognition.

1. Reinforcement Learning:- team of learning automata: Current computer vision systems whose basic methodology is open loop or *filter* type typically use image segmentation followed by object recognition algorithms. These systems are not robust for most real-world applications. In contrast, the system presented here achieves robust performance by using reinforcement learning to induce a mapping from input images to corresponding segmentation parameters. This is accomplished by using the confidence level of model matching as a reinforcement signal for a *team of learning automata* to search for segmentation parameters during training. The use of the recognition algorithm as part of the evaluation function for image segmentation gives rise to significant improvement of the system performance by automatic generation of recognition strategies. The system is verified through experiments on sequences of indoor and outdoor color images with varying external conditions.

2. Delayed Reinforcement Learning: Object recognition is a multi-level process requiring a sequence of algorithms at low, intermediate and high levels. Generally, such systems are open loop with no feedback between levels and assuring their robustness is a key challenge in computer vision and pattern recognition research. A robust closed-loop system based on "delayed" reinforcement learning is introduced. The parameters of a multi-level system employed for model-based object recognition are learned. The method improves recognition results over time by using the output at the highest level as feedback for the learning system. Learning the parameters of image segmentation and feature extraction and thereby recognizing 2-D objects have experimentally validated it. The approach systematically controls feedback in a multi-level vision system and shows promise in approaching a long-standing problem in the field of computer vision and pattern recognition.

3. Use of Domain Knowledge in Reinforcement Learning: We have developed a general approach to image segmentation and object recognition that can adapt the image

segmentation algorithm parameters to the changing environmental conditions. Segmentation parameters are represented using a team of generalized stochastic learning automata and learned using connectionist reinforcement learning techniques. The edge-border coincidence measure is first used as reinforcement for segmentation evaluation to reduce computational expenses associated with model matching during the early stage of adaptation. This measure alone, however, cannot reliably predict the outcome of object recognition. Therefore, it is used in conjunction with model matching where the matching confidence is used as a reinforcement signal to provide optimal segmentation evaluation in a closed-loop object recognition system. The adaptation alternates between global and local segmentation processes in order to achieve optimal recognition performance. Results are presented for both indoor and outdoor color images where the performance improvement over time is shown for both image segmentation and object recognition.

4. Adaptive SAR ATR system based on Reinforcement Learning: Target recognition is a multi-level process requiring a sequence of algorithms at low, intermediate and high levels. Generally, such systems are open loop with no feedback between levels and assuring their performance at the given Probability of Correct Identification (*PCI*) and Probability of False Alarm (*Pf*) is a key challenge in computer vision and pattern recognition research. We have developed a robust closed-loop system for recognition of SAR images based on reinforcement learning. The parameters in model-based SAR target recognition are learned. The method meets performance specifications by using *PCI* and *Pf* as feedback for the learning system. Learning the parameters of the recognition system for SAR imagery has experimentally validated the approach, successfully recognizing articulated targets, targets of different configuration and targets at different depression angles.

5. Adaptive Recognition for Autonomous Navigation: Current machine perception techniques that typically use segmentation followed by object recognition lack the required robustness to cope with the large variety of situations encountered in real-world navigation. Many existing techniques are brittle in the sense that even minor changes in the expected task environment (e.g., different lighting conditions, geometrical distortion,

etc.) can severely degrade the performance of the system or even make it fail completely. We have developed a system that achieves robust performance by using local reinforcement learning to induce a highly adaptive mapping from input images to segmentation strategies for successful recognition. This is accomplished by using the confidence level of model matching as reinforcement to drive learning. Local reinforcement learning gives rises to better improvement in recognition performance. The system is verified through experiments on a large set of real images of traffic signs.

Journal Publications

1. J. Peng and B. Bhanu, "Closed loop object recognition using reinforcement learning," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 20, No. 2, pp. 139-154, 1998.

2. J. Peng and B. Bhanu, "Delayed reinforcement learning for adaptive image segmentation and feature extraction," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 28, No. 3, pp. 482-488, 1998.

3. B. Bhanu, Y. Lin, G. Jones and J. Peng, "Adaptive target recognition," *International Journal of Machine Vision and Applications,* Vol. 11, No. 6, pp. 289-299, 2000

4. J. Peng and B. Bhanu, "Learning to perceive objects for autonomous navigation," *Autonomous Robots*, Vol. 6, No. 2, pp. 187-201, 1999.

5. B. Bhanu and J. Peng, "Adaptive integrated image segmentation and object recognition," *IEEE Transactions on Systems, Man and Cybernetics- Part C*, Vol. 30, No. 4, pp. 427-441, 2000.

6. J. Peng and B. Bhanu, "Local discriminative learning for pattern Recognition," *Pattern Recognition*, Vol. 34, No. 1, pp. 139-150, 2001.

2.4 Learning Concepts in Images and Videos

We have developed two major ideas and approaches that relate low-level image features with high-level visual concepts in images to accomplish image based queries in large databases. The challenge has been to overcome the subjective nature of human image interpretation.

Key idea 1: Probabilistic Feature Relevance Learning for Content-Based Image Retrieval: Most of the current image retrieval systems use "one-shot" queries to a database to retrieve similar images. Typically a K-nearest neighbor kind of algorithm is used, where weights measuring feature importance along each input dimension remain fixed (or manually tweaked by the user), in the computation of a given similarity metric. However, the similarity does not vary with equal strength or in the same proportion in all directions in the feature space emanating from the query image. The manual adjustment of these weights is time consuming and it requires a very sophisticated user. We have developed a novel probabilistic method that enables image retrieval procedures to automatically capture feature relevance based on user's feedback and that is highly adaptive to query locations. This feedback, in the form of accept or reject examples generated in response to a query image, is used to locally estimate the strength of features along each dimension while taking into consideration the correlation between features. This results in local neighborhoods that are constricted along feature dimensions that are most relevant, while elongated along less relevant ones. In addition to exploring and exploiting local principal information, the system seeks a global space for efficient independent feature analysis by combining such local information. We provide experimental results that demonstrate the efficacy of our technique using both simulated and real-world data.

Key Idea 2: Learning Visual Concepts: We have developed an approach for learning visual concepts in images based on statistical learning techniques for relevance feedback and fuzzy clustering. The fuzzy clustering technique successfully handles conditions where the concept features overlap. In this work, we address the problem of incorporating prior experience of the retrieval system to improve the performance on future queries. We develop a semi-supervised fuzzy clustering method to learn class

distribution (meta knowledge) in the sense of high-level concepts from retrieval experience. Using fuzzy rules, we incorporate the meta knowledge into a probabilistic relevance feedback approach to improve the retrieval performance. Results on synthetic and real databases show that our approach provides better retrieval precision compared to the case when no retrieval experience is used.

Journal Publications

1. J. Peng, B. Bhanu and S. Qing, "Probabilistic feature relevance learning for content-based image retrieval," *Computer Vision and Image Understanding*, Vol. 75, No. 1/2, pp. 150-164, 1999. *(Special Issue of Content-Based Access of Image and Video Libraries)*

2. J. Peng and B. Bhanu, "Independent feature analysis for image retrieval," *Pattern Recognition Letters*, Vol. 22, No. 1, pp. 63-74, 2001.

3. B. Bhanu and A. Dong, "Concept learning with fuzzy clustering and relevance feedback," *Engineering Applications of Artificial Intelligence*, Vol. 15, No. 2, pp. 123-138, 2002.

3. PERSONNEL SUPPORTED:

Bir Bhanu, Grinnell Jones, Jing Peng, Michael Boshra, Sohail Nadami, Jingchun Liu, Ju Han, Xuejun Tan, Yingqing Lin, Anlei Dong, Lynne Cochran, Daniel Morrione, Ping Liang, Jim Press, Daniel Rowe.

4. PUBLICATIONS (March 15, 1997 to 31 August 2002)

4.1 Journal Papers Published

- J. Peng and B. Bhanu, "Closed loop object recognition using reinforcement learning," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 20, No. 2, pp. 139-154, 1998.

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- B. Bhanu and G. Jones, "Recognizing target variants and articulations in synthetic aperture radar images," *Optical Engineering*, Vol. 39, No. 3, pp. 712-723, 2000.

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- G. Jones and B. Bhanu, "Recognizing articulated targets in SAR images," *Pattern Recognition*, Vol. 34, No. 2, pp. 469-485, 2001.

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- B. Bhanu and G. Jones III., “Multiple look angle SAR recognition,” *International Journal of Imaging and Graphics*. Accepted.

- B. Bhanu and Y. Lin, “Stochastic models for recognition of occluded objects,” *Pattern Recognition*, Revised September 2002.

4.2 Book Chapters

- J. Peng and B. Bhanu, “Pattern classification based on local learning,” In *Advances in Pattern Recognition*, A. Amin, D, Dori, P. Pudil and H. Freeman, (Eds.), pp. 882-889, Springer, 1998.

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- B. Bhanu and B. Tian, "Stochastic models for recognition of articulated objects," *Proceedings IEEE International Conference on Image Processing*, pp. 847-850, 1997.

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